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Iron Status of Vegetarian Children: A Review of Literature

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Vegetarians · Children · Iron status · Hemoglobin · Ferritin

Abstract
Background: Iron is considered a nutrient of concern for vegetarians. In children, inadequate iron status may lead to anemia and poor growth. ***Summary:*** Thirteen original manuscripts met the inclusion criteria. Various biochemical markers of iron status, such as hemoglobin (Hb) and serum ferritin, were used. Seven of the 13 studies reported the prevalence of iron deficiency separately for vegetarians and non-vegetarians. Five out of 7 showed a higher prevalence of iron deficiency among the vegetarian participants, while the other 2 showed a higher prevalence of iron deficiency among non-vegetarians. A wide range of iron deficiency prevalence, from 4.3% of vegetarian participants in one study to 73% having ferritin <10 μg/L in another study, was found. Hb data showed almost as wide variations from 0% of children having Hb values lower than 11 g/dL to 47.5% having Hb values below 3rd percentile. ***Key Messages:*** The prevalence of iron deficiency among vegetarian children varies considerably from one study to another. The wide variation in the prevalence of inadequate iron status was consistent for studies from industrial and developing countries. The physiological significance of low iron status among vegetarians reported in some studies is unknown.

Introduction

The term "vegetarian" is used to describe multiple diet types, including semi-vegetarian, pesco-vegetarian, lacto-vegetarian, ovo-vegetarian, lacto-ovo-vegetarian, and vegan. Semi-vegetarians include small amounts of meat, mainly from fish and poultry. Pesco-vegetarians ingest some fish, in addition to foods of animal and plant origin. Milk and dairy products are ingested by lacto-vegetarians, ovo-vegetarians include eggs, whereas lacto-ovo-vegetarians ingest both dairy, including milk, and eggs. Individuals who adhere to vegan diets exclude all meat and animal products. There are additional variations within each of the above categories of diet preference. For example, some individuals who consider themselves vegans do not eat honey or other bee products while others just limit their dietary exclusion to dairy and eggs.

The vegetarian lifestyle is not exclusive to adults. According to a national survey conducted online in 2014 by Harris Poll, about 4% of children in the United States between the ages of 8 and 18 are vegetarian [1]. Data gathered in the same poll showed that 1% of children follow a vegan diet.

Even though vegetarian lifestyle is associated with a number of advantages, such as lower risk factors and disease prevalence of some chronic health conditions in adults, vegetarians do have a high risk of a deficiency of some nutrients, including iron [2–5]. Iron deficiency is of

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importance because iron plays a significant role in human growth and development. Its main role in the body is to participate in oxygen transport as a component of heme in erythrocytes [6]. Iron is needed for the citric acid cycle in energy metabolism and is a cofactor for many enzymes. Iron is also essential in DNA synthesis [6].

The most readily absorbed type of iron is heme iron which comes from meat, poultry, and fish. Therefore, since these foods are not consumed by vegetarians, except for semi- and pesco-vegetarians, vegetarians consume the less-absorbable non-heme iron. Furthermore, plant foods contain several iron-absorption inhibitors. They include phenolic compounds, oxalates, and phytates. Food especially rich in the above-listed iron absorption inhibitors include grains, especially whole grains, beans and nuts, many vegetables including spinach and parsley, but also spices and condiments such as oregano, cinnamon, tea, coffee, red wine, and cocoa [7].

Getting sufficient amounts of iron from non-heme iron sources can be a challenge. This is especially true considering that the iron requirements for vegetarians are about 1.8 times higher, compared to non-vegetarians [8].

Although several studies have reported the assessed iron status of vegetarian children and adolescents, no review of literature regarding the iron status among vegetarian children and teenagers has been conducted to our knowledge. Thus, the goal of this study was to review published studies that reported the iron status among vegetarian children and adolescents. The specific objectives included: (1) assessing the iron status among vegetarian children, (2) evaluating the deficiency prevalence among vegetarian children, and (3) comparing the iron status between vegetarian and non-vegetarian children.

Methods

The goal of the literature search was to identify all published manuscripts that reported the iron status among vegetarian children and/or adolescents up to the end of October 2016. The date of publication was not restricted. Relevant manuscripts were identified via PubMed and Medline via Ovid searches. Multiple terms were used to search for relevant manuscripts. They included vegetarian (Title) AND iron (Title/Abstract), 73 matches; vegan (Title) AND iron (Title/Abstract), 11 matches; vegetarian (Title) AND nutrient (Title/Abstract), 60 matches, and vegan (Title) AND nutrient (Title/Abstract), 18. Thus, the total number of identified manuscripts was 162. Identified manuscripts were considered relevant for inclusion if the article was an original study with any type of vegetarian and/or vegan children and/or adolescents and if they contained data on the iron status of the participants, regardless of the types of biochemical assessment used. Manuscripts that assessed only the intake of iron but did not report any biochemical assessment of iron status were excluded. Also, reports on iron deficiency status in adults, reviews, commentaries, letters to editors, and position papers were excluded. Both authors screened the titles and abstracts of the 162 identified manuscripts. Eleven of them met the above-mentioned inclusion criteria. Two additional manuscripts were identified via cross-reference search. Thus, the findings are based on 13 original studies published between 1982 and 2013.

Findings

Thirteen manuscripts met the inclusion criteria. The included studies were conducted in 9 different countries: Canada, China, England, Ghana, Great Britain, Poland, Slovakia, Sweden, Taiwan, and the United States of America. The number of total participants in the studies ranged from 39 to 1,520. The number of vegetarian children in the studies ranged from 20 to 95. The age of participants in the studies ranged from 4 months to 20 years. Only 8 of the 12 studies reported gender-specific data. The split between participating boys and girls in these studies were nearly 50:50.

The biochemical markers used to determine the iron status in the various manuscripts were: hemoglobin (Hb), serum ferritin, serum iron, total iron binding capacity (TIBC), transferrin level, and transferrin saturation. The majority of studies looked at the Hb level (11 studies) and the level of serum ferritin (10 studies). Findings for Hb, ferritin, serum iron, and transferrin saturation are summarized in Tables 1–4, respectively.

Authors of the different studies did not always use consistent criteria for what constituted iron deficiency. This was in part due to assessing the iron status among participants of different age and gender. For example, definitions of iron deficiency in different studies, using Hb were: <11.0 g/dL [9, 10], <11.7 g/L [11], <12.0 g/L [12], <11.0 g/dL for 0.5–5 years and <11.5 g/dL for >5–11 years [13]. In one study, Hb below the 3rd percentile of the Dallman reference curves was used as a marker of deficiency [16]. Similarly, the cutoff criteria for serum ferritin included <10.0 μg/L [9, 17], <12.0 μg/L [9, 11], <15.0 mg/L [18], <15.0 ng/mL [13, 19], <12.0 μg/L for 1–3 years and <15.0 μg/L for >3 years [10], <15.0 μg/L for girls and <20.0 μg/L for boys [15]. The same inconsistencies were found for other markers of iron status.

Iron Status of Vegetarian Children

In all of the studies, vegetarian children's mean or median Hb level was above the value set as the deficiency criteria. However, Hb ranges and standard deviation of the

Table 1. Iron status among vegetarian children and adolescents by Hb level

Author, year	Country	Sample (number and age)	Diet adherence/length of adherence	Iron deficiency criteria	Prevalence of iron deficiency	Iron status
Thane and Bates [9], 2000	Great Britain	*n* = 1,351 Vegetarian: *n* = 44, age: 1.5–4.5 years (*n* = 25, <3 years, *n* = 19, >3 years) OM: *n* = 1,307 (*n* = 668, <3 years; *n* = 639, >3 years)	Vegetarian inclusion criteria: not having eaten meat during a 4-day period of dietary record keeping	Low Hb level: <11 g/dL	Vegetarian <3 years old: 18% Vegetarian ≥3 years old: 0% OM <3 years old: 10% OM ≥3 years old: 6%	Vegetarian: mean (SD) Hb for <3 years old = 11.8 (0.9) g/dL Mean (SD) Hb for ≥3 years old = 12.1 (0.6) g/dL OM: mean (SD) Hb for <3 years old = 12.1 (0.9) g/dL Mean (SD) Hb for ≥3 years old = 12.3 (0.9) g/dL
Gorczyca et al. [10], 2013	Poland	*n* = 40 Vegetarian: *n* = 22 OM: *n* = 18 Age: 2–18 years	Vegetarian inclusion criteria: ≥1 year of vegetarian diet Median length of vegetarian diet: 3 years and 5 months	Anemia: Hb level <11.0 g/dL IDA: Hb level <11.0 g/dL with ID based on ferritin level	Vegetarian: Anemia: 4.5% IDA: 9.1% OM: Anemia: 5.6% IDA: 0%	Vegetarian: median Hb = 12.6 g/dL, Hb range = 9.2–15.3 g/dL OM: median Hb = 12.9 g/dL Hb range = 10.3–17.5 g/dL
Donovan and Gibson et al. [11], 1995	Canada	*n* = 124 LOV: *n* = 79 Mean (SD) age = 17.5 (1.4) SV: *n* = 16 Mean (SD) age = 18.4 (1.8) OM: *n* = 29 Mean (SD) age: 18.2 (1.4) Age: 14–19 years	LOV inclusion criteria: red meat, poultry, and fish consumed <1/months SV inclusion criteria: red meat consumed <1/months Median length of vegetarian diet: 4.7±5.3 years	Hb <117 g/L	LOV: 2.5%, SV: 0%, OM: 3.5%	LOV: mean (SD) Hb = 138±9 g/L SV: mean (SD) Hb = 135 (8) g/L OM: mean (SD) Hb = 138 (9) g/L
Krajčovičová-Kudláčková et al. [12], 1997	Slovakia	*n* = 58 Vegetarian: *n* = 26 11 boys and 15 girls OM: *n* = 32 14 boys and 18 girls Age: 11–14	Average length of vegetarian diet: 2.81 years	Hb <120 g/L	Vegetarian: 23% OM: 3%	Vegetarian: mean (SE) 135.4±1.6 g/L OM: mean (SE) 142.0±1.3 g/L
Osei-Boadi et al. [13], 2012	Ghana	*n* = 52 Vegetarian: *n* = 26 OM: *n* = 26 Age: 9 months to 11 years	Vegetarian inclusion criteria: lifelong exclusion of meat, fish, eggs, or any other animal source of food after exclusive breastfeeding	Anemia: Hb <11.0 g/dL for 0.5–5 years and <11.5 g/dL for >5–11 years IDA: ferritin <15 ng/mL and Hb <11.5 g/dL	Vegetarian: Anemia: 23.1% ID: 3.8% OM: Anemia: 26.9% IDA: 3.8%	Vegetarian: mean (SD) Hb = 11.8 (1.1) g/dL OM: mean (SD) Hb = 11.6 (1.1) g/dL
Dwyer et al. [14], 1982	USA	*n* = 39 Macrobiotic vegetarian (*n* = 9 vegan and *n* = 18 consuming small amount of fish and other animal products) LOV: *n* = 12 Seventh-Day Adventist age: 0.8–8.4 years Mean (SD) age = 4.0 (1.9) years	Not reported	Hb <11.2 g/100 mL at 0.5 years and up and <11.6 g/100 mL at 8 years	8% (data only for 24 vegetarian children with no specific information to which children)	Mean (SD) Hb level = 12.4 (1.0) g/100 mL (data for 24 vegetarian children)

Table 1. (continued)

Author, year	Country	Sample (number and age)	Diet adherence/length of adherence	Iron deficiency criteria	Prevalence of iron deficiency	Iron status
Thane et al. [15], 2003	Great Britain	*n* = 1,520 Age: 4–18 years Number of vegetarians not specified	Not reported	Data reported only for Hb in girls: <115 g/L for 4–12 years, <120 g/L for ≥13 years	Vegetarian girls: 0% for 11–14 years old, 30% for 15–18 years OM: 3% for 11–14 years old, 4% for 15–18 years old	No data on vegetarian boys and girls reported
Nathan et al. [16], 1996	Great Britain	*n* = 100 Vegetarian: *n* = 50 LOV: *n* = 27) SV: *n* = 23 OM: *n* = 50 Age: 7–10 years (assessment was done on 35 vegetarians and 35 OM)	Vegetarian inclusion criteria: ≥3 months of vegetarian diet (includes dairy products, eggs, and fish, but no meat or meat products)	<3rd percentile for Hb	Vegetarian: 47.5% OM: 33%	Vegetarian: mean (SE) Hb = 118.6 (1.8) g/L OM: mean (SE) Hb = 124.1 (2.0) g/L
Leung et al. [18], 2001	China	*n* = 51 Vegetarian: *n* = 51 Age: 4–14 years (*n* = 10, <7 years, *n* = 24, between 7 and 11 years and *n* = 17, between 12 and 14 years)	Vegetarian inclusion criteria: ≥1 year of vegetarian diet. All were vegetarians for >2 years	Unclear	Anemia (no definition): 8.5% ID (no definition): 4.3%	Mean (SD) Hb for <7 years old = 12.2 (1.3) g/dL, for 7–11 years old = 13.5 (0.9) g/dL, for >11 years old = 13.6 (1.1) g/dL Mean (SD) ferritin for <7 years old = 27 (12) for 7–11 years old = 35 (20) for >11 years old = 36 (20)
Taylor et al. [20], 2004	England	*n* = 198 Vegetarian: *n* = 20 OM: *n* = 178 (60 low, 59 middle, and 59 high meat consumers) Age 4–5 months through 24 months	No meat intake based on 7-day recall	Not reported	Not reported	Vegetarians: mean (SD) Hb at 4–5 months = 120.3 (15.55), at 12 months = 119.2 (11.52), at 24 months = 123.7 (7.31) OM: mean (SD) ranged from 112.9 (12.33) to 116.6 (15.59) for low to high meat consumers
Yen et al. [23], 2008	Taiwan	*n* = 49 Vegetarian: *n* = 21 LOV: *n* = 18 OV: *n* = 3 OM: *n* = 28 Age: 2–6 years	Vegetarian inclusion criteria: ≥6 months of vegetarian diet and planning to continue Median length of vegetarian diet: 4 years and 6 months	Not reported	Not reported	Vegetarian: mean (SD) Hb = 12.8 (1.0) g/dL OM: mean (SD) Hb = 13.2 (1.1) g/dL

ID, iron deficiency; IDA, iron deficiency anemia; Hb, hemoglobin, TIBC, total iron-binding capacity; LOV, lacto-ovo-vegetarian; SV, semi-vegetarian, OM, omnivore; OV, ovo-vegetarian; LV, lacto-vegetarian.

mean indicate wide discrepancies among participants and they also indicate that some participants were significantly below the accepted normal values (e.g., 9.2 g/dL) [10].

The mean and/or median ferritin concentration varied considerably among studies. For example, in one Polish study the median ferritin concentration was just 9.61 μg/L, ranging from 1.6 to 54.1 μg/L [10]. However, in another study from Poland, the mean ferritin among vegetarian children was 31.2 ng/mL with a range of 13.2–76.4 ng/mL [19]. The mean and/or median transferrin satura-

Table 2. Iron status among vegetarian children using serum ferritin

Author, year	Country	Sample (number and age)	Diet adherence/ length of adherence	Iron deficiency criteria	Prevalence of iron deficiency	Iron status
Thane and Bates [9], 2000	Great Britain	*n* = 1,351 Vegetarian: *n* = 44 Age: 1.5–4.5 years (25 <3 years, 19 >3 years) OM: *n* = 1,307 (668 <3 years, 639 >3 years)	Vegetarian inclusion criteria: not having eaten meat during a 4-day period of dietary record keeping	Serum ferritin level <12 and <10 μg/L	Vegetarian: <3 years old: 73 and 64%, respectively, ≥3 years old: 40 and 20%, respectively OM: <3 years old: 34 and 24%, respectively, ≥3 years old: 27 and 16%, respectively	Vegetarian: mean serum ferritin for <3 years old = 8.0 g/dL Mean serum ferritin for ≥3 years old = 13.0 g/dL OM: mean serum ferritin for <3 years old = 16.0 g/dL Mean serum ferritin for ≥3 years old = 19.0 g/dL
Gorczyca et al. [10], 2013	Poland	*n* = 40 Vegetarian: *n* = 22 OM: *n* = 18 Age: 2–18 years	Vegetarian inclusion criteria: ≥1 year of vegetarian diet Median length of vegetarian diet: 3 years and 5 months	Serum ferritin level <12.0 μg/L for 1–3 years and <15.0 μg/L for >3 years	Vegetarian: 36.4% OM: 11.1%	Vegetarian: median serum ferritin = 9.61 μg/L, range = 1.6–54.1 μg/L OM: median serum ferritin = 36.1 μg/L, range = 9.52–167.4 μg/L
Donovan and Gibson [11], 1995	Canada	*n* = 124 LOV: *n* = 79 Mean age: 17.5 years SV: *n* = 16 Mean age: 18.4 OM: *n* = 29 Mean age: 18.2	LOV inclusion criteria: red meat, poultry, and fish consumed <1/month SV inclusion criteria: red meat consumed <1/month but had small amounts of poultry and fish Median length of vegetarian diet: 4.7±5.3 years	Plasma ferritin <12 μg/L	LOV: 29.1% SV: 43.8% OM: 17.2%	LOV: geometric mean plasma ferritin = 18.2 μg/L SV: geometric mean plasma ferritin = 15.5 μg/L OM: geometric mean plasma ferritin = 20.0 μg/L
Osei-Boadi et al. [13], 2012	Ghana	*n* = 52 Vegetarian: *n* = 26 OM: *n* = 26 Age: 9 months to 11 years	Vegetarian inclusion criteria: lifelong exclusion of meat, fish, eggs, or any other animal source of food after exclusive breastfeeding	Ferritin <15 ng/mL	Vegetarian: 11.1% OM: 15.8%	Vegetarian: mean (SD) plasma ferritin = 34.05 (25.9) ng/mL OM: mean (SD) plasma ferritin = 59.15 (48.2) ng/mL
Thane et al. [15], 2003	Great Britain	*n* = 1,520 Age: 4–18 years Number of vegetarians was not specified	Not reported	Serum ferritin: <15 μg/L for girls, and <20 μg/L for boys	Vegetarian: girls aged 11–14 years: 20% Girls aged 15–18 years: 40%	Data specific for vegetarians not reported
Leung et al. [18], 2001	China	*n* = 51 *n* = 10, <7 years old *n* = 24, between 7 and 11 years old *n* = 17, between 12 and 14 years old	Vegetarian inclusion criteria: ≥1 year of vegetarian diet All were vegetarians for >2 years	Unclear	4.3% had ferritin <10 mg/L	Mean (SD) ferritin for <7 years old = 27 (12) μg/L Mean ferritin for 7–11 years old = 35 (20) μg/L Mean (SD) ferritin for >11 years old = 36 (20) μg/L
Laskowska-klita et al. [19], 2011	Poland	*n* = 50 Vegetarian: *n* = 32 Age: 6.5±4.2 years OM: *n* = 18 Age: 7.9±2.7 years	Not reported	Not reported	Not reported	Mean (SD) vegetarian ferritin = 31.2 (13.4) ng/mL Vegetarian ferritin range = 13.2–76.4 ng/mL

Table 2. (continued)

Author, year	Country	Sample (number and age)	Diet adherence/ length of adherence	Iron deficiency criteria	Prevalence of iron deficiency	Iron status
Taylor et al. [20], 2004	England	*n* = 198 Vegetarian: *n* = 20 OM: *n* = 178 (60 low, 59 middle, and 59 high meat consumers) Age 4–5 months through 24 months	No meat intake based on 7-day recall	Not reported	Not reported	Vegetarians: mean (SD ferritin = 49.5 (40.6) μg/L at 4–5 months old, 24.9 (13.4) μg/L at 24 months, and 21.92 (7.9) μg/L at 24 months OM: mean (SD) ranged from 37.7 (22.4) μg/L for middle tertile to 41.4 (21.9) μg/L for highest tertile at 4–5 months; 27.0 (15.2) μg/L for the middle tertile to 32.1 for the highest tertile at 12 months, and 20.9 (8.9) μg/L in the highest tertile to 23.5 (10.1) μg/L in the lowest tertile at 24 months
Yen et al. [23], 2008	Taiwan	*n* = 49 Vegetarian: *n* = 21 LOV: *n* = 18 OV: *n* = 3 OM: *n* = 28 Age: 2–6 years	Vegetarian inclusion criteria: ≥6 months of vegetarian diet and planning to continue Median length of vegetarian diet: 4 years and 6 months	Not reported	Not reported	Mean (SD) vegetarian serum ferritin = 26.6 (13.7) ng/mL Mean OM: serum ferritin = 38.7 (24.9) ng/mL

ID, iron deficiency; IDA, iron deficiency anemia; TIBC, total iron-binding capacity; LOV, lacto-ovo-vegetarian; SV, semi-vegetarian; OM, omnivore; OV, ovo-vegetarian; LV, lacto-vegetarian.

tion were modestly above 15% (ranging from 16.6 to 26%) in all 3 studies that used this assessment method [11, 15, 19].

Iron Deficiency Prevalence among Vegetarian Children

There was a wide range in the prevalence of iron deficiency between the different studies that utilized Hb as a marker of iron status. For example, none of the semi-vegetarians and 2.5% among lacto-ovo-vegetarian adolescents in Canada were deficient [11]. The above results are contrasted by those from a British study in which about 47.5% of vegetarian children had Hb values indicative of a deficiency [16]. Similarly, when ferritin was used as a marker of iron status, the deficiency prevalence ranged from 4.3% among a sample composed of children and adolescents, 4–14 years old, from China to 73% among children younger than 3 years old from Great Britain [9, 18].

Discrepancies in the prevalence of deficiency were also noticed for other biomarkers. For serum iron, the deficiency prevalence ranged from 4.5% among Polish vegetarian children and teens to 58% among those from Slovakia [11, 12]. Data based on TIBC showed the deficiency prevalence ranging from 6.6% in Sweden to 66.7% among lacto-ovo-vegetarians and 62.5% among semi-vegetarians in Canada [10, 17]. Also, when transferrin saturation was used as a marker of iron status, the deficiency prevalence ranged from 6.6% in Sweden to 66.7% among lacto-ovo-vegetarian teens in Canada [10, 17]. Lastly, high prevalence of transferrin saturation values below normal were found among all 3 studies. This prevalence ranged from 20 to 60%, depending on the study location and age of participants [15, 19].

Comparison of Iron Status among Vegetarian and Non-Vegetarian Children

Eight of the 11 studies reported the iron status using Hb among both vegetarian and non-vegetarian children. In 5 of these 8 studies, vegetarian participants had a higher iron deficiency prevalence [9, 10, 12, 16, 17].

Table 3. Iron status among vegetarian children and adolescents by serum iron

Author, year	Country	Sample (number and age)	Diet adherence/ length of adherence	Iron deficiency criteria	Prevalence of iron deficiency	Iron status
Gorczyca et al. [10], 2013	Poland	*n* = 40 Vegetarian: *n* = 22 OM: *n* = 18 Age range: 2–18 years	Vegetarian inclusion criteria: ≥1 year of vegetarian diet Median length of vegetarian diet: 3 years and 5 months	Serum iron <20.0 μmol/L	Vegetarian: 4.5% OM: 22.2%	Vegetarian: median serum iron = 74.95 μmol/L, range = 9.7–69.4 μmol/L OM: median serum iron = 95.3 μmol/L, range = 53.5–136.0 μmol/L
Donovan and Gibson [11], 1995	Canada	*n* = 124 LOV: *n* = 79 Mean (SD) age: 17.5 (1.4) SV: *n* = 15 Mean (SD) age = 18.4 (1.8) OM: *n* = 29 Mean (SD) age: 18.2 (1.4)	LOV: inclusion criteria: red meat, poultry, and fish consumed <1/month SV: inclusion criteria: red meat consumed <1/month Median length of vegetarian diet: 4.7±5.3 years	Serum iron <11 μmol/L	LOV: 28.2% SV: 31.3% OM: 28.6%	LOV: geometric mean (range) of serum iron = 13.5 (13.2–13.8) μmol/L SV: geometric mean (range) of serum iron = 12.9 (12.1–13.7) μmol/L OM: geometric mean (range) of serum iron = 14.1 (13.6–14.7) μmol/L
Krajčovičová-Kudláčková et al. [12], 1997	Slovakia	*n* = 58 Vegetarian: *n* = 26 OM: *n* = 32 Age range: 11–14	Not reported Average length of vegetarian diet: 2.81 years	Iron <18.0 μmol/L	Vegetarian: 58% OM: 9%	Vegetarian: mean iron 15.9 μmol/L OM: mean iron 22.5
Dwyer et al. [14], 1982	USA	*n* = 14 macrobiotic vegetarians and vegans Mean age: 4.0±1.9 years	Not reported	Serum iron <85 μg/100 mL	Not reported	Mean (SD) iron = 86 (38) μg/100 mL
Laskowska-klita et al. [19], 2011	Poland	*n* = 50 Vegetarian: *n* = 32 Age: 6.5±4.2 years OM: *n* = 18 Age: 7.9±2.7 years	Not reported	Serum iron <6.6 μmol/L	Vegetarian: 20% OM: not reported	Vegetarian mean (SD) serum iron = 14.5 (8.2) μmol/L OM: not reported
Taylor et al. [20], 2004	England	*n* = 198 Vegetarian: *n* = 20 OM: *n* = 178 (60 low, 59 middle, and 59 high meat consumers) Age 4–5 months through 24 months	No meat intake based on 7-day recall	Not reported	Not reported	Vegetarians: mean (SD) = 8.0 (5.4) μmol/L at 4–5 months, 8.2 (1.5) μmol/L at 12 months and 15.3 (5.1) μmol/L at 24 months OM: mean (SD) ranged from 6.0 (3.6) μmol/L for the middle tertile to 8.0 (3.9) μmol/L for the highest tertile at 4–5 months, 8.6 (4.6) μmol/L for the middle tertile to 13.0 (3.4) μmol/L for the highest tertile at 12 months, and 13.4 (5.4) μmol/L for the middle tertile to 15.1 (5.5) μmol/L for the highest tertile at 24 months
Yen et al. [23], 2008	Taiwan	*n* = 49 Vegetarian: *n* = 21 LOV: *n* = 18 OV: *n* = 3 OM: *n* = 28 Age: 2–6 years old	Vegetarian inclusion criteria: ≥6 months of vegetarian diet and planning to continue Median length of vegetarian diet: 4 years and 6 months	Not reported	Not reported	Vegetarian: mean (SD) serum iron = 86.2 (37.2) μg/dL OM: mean (SD) serum iron = 90.9 (40.9) μg/dL

ID, iron deficiency; IDA, iron deficiency anemia; TIBC, total iron-binding capacity; LOV, lacto-ovo-vegetarian; SV, semi-vegetarian; OM, omnivore; OV, ovo-vegetarian; LV, lacto-vegetarian.

Table 4. Iron status among vegetarian children and adolescents by transferrin saturation

Citation	Country	Sample (number and age)	Diet adherence/ length of adherence	Iron deficiency criteria	Prevalence of iron deficiency	Iron status
Donovan and Gibson [11], 1995	Canada	*n* = 124 LOV: *n* = 79 Mean (SD) age = 17.5 (1.4) SV: *n* = 16 Mean (SD) age = 18.4 (1.8) OM: *n* = 29 Mean (SD) age: 18.2 (1.4)	LOV: inclusion criteria: red meat, poultry, and fish consumed <1/month SV: inclusion criteria: red meat consumed <1/month Median length of vegetarian diet: 4.7±5.3 years	Transferrin saturation <16%	LOV: 34.6% SV: 50.0% OM: 39.3%	LOV: geometric mean transferrin saturation = 17.8% SV: geometric mean transferrin saturation = 16.6% OM: geometric mean transferrin saturation = 18.2%
Thane et al. [15], 2003	Great Britain	*n* = 1,520 Age: 4–18 years number of vegetarians not specified	Not reported	Transferrin saturation <15%	Vegetarian girls: 20% for 11–14 years old, 60% for 15–18 years old, OM girls: 17% for 11–14 years old, 25% for 15–18 years old Data for boys not reported	Data by diet adherence not reported
Laskowska-klita et al. [19], 2011	Poland	*n* = 50 Vegetarian: *n* = 32 Age: 6.5±4.2 years OM: *n* = 18 Age: 7.9±2.7 years	Not reported	Low transferrin saturation level: <15.0%	Vegetarian: 20% Values for OM children not reported	Vegetarian: mean (SD) transferrin saturation = 25.1 (14.8) μmol/L, range = 5.6–60.4 μmol/L Values for OM children not reported

ID, iron deficiency; IDA, iron deficiency anemia; TIBC, total iron-binding capacity; LOV, lacto-ovo-vegetarian; SV, semi-vegetarian; OM, omnivore; OV, ovo-vegetarian; LV, lacto-vegetarian.

The opposite was true for 2 other studies [11, 13]. Deficiency prevalence was not reported in one study [20].

The biggest differences in Hb concentration were reported in studies from Slovakia and Great Britain [12, 16]. The prevalence of Slovakian vegetarian boys and girls with Hb below 120 g/L was 23%, compared to just 3% among non-vegetarian adolescents [12]. In Great Britain, this difference was 47.5% among vegetarian children, compared to 33% among non-vegetarians [16]. The prevalence of low Hb was somewhat similar among vegetarians and non-vegetarians from other studies. For example, 4.5 and 5.6%, Polish vegetarian and non-vegetarian children, respectively, had Hb indicative of a deficiency in a study by Gorczyca et al. [10]. Similarly, 23.1 and 26.9%, vegetarian and non-vegetarian Ghanaian children, respectively, had anemia (Hb <11 g/dL) [13].

On the contrary, the prevalence of iron deficiency, assessed by ferritin concentration, was more than 3 times higher among vegetarian versus non-vegetarian children in Poland (36.4 vs. 11.1%) [10]. Similarly, among children from Great Britain, iron deficiency was almost 3 times as high among vegetarian versus non-vegetarian children ≥3 years of age (64 vs. 24%) and about twice as prevalent among children younger than 3 years of age (73 vs. 34%) in one study [9]. The study from Ghana was the only one with opposite results [13]. Non-vegetarian children in that study had a higher prevalence of deficiency based on ferritin concentration (15.8% compared to 11.1% among vegetarians). However, even in this study, the mean ferritin concentration was higher among non-vegetarian, compared to vegetarian children (59.15 vs. 34.05 ng/mL).

Discussion

In this review, we assessed the prevalence of iron deficiency among vegetarian children. We also compared the prevalence of deficiency among non-vegetarian children. The comparison was somewhat difficult due to a number of differences among studies regarding the definition of vegetarianism, the types of utilized biomarkers and the definitions of deficiency. For example, the definition of vegetarians was as lenient as the "absence of all meat and meat products during the 4-day period," [9] and as strict as "have eaten any meat, fish, eggs or any animal source food all of his/her life after the period of exclusive breastfeeding" [13]. The criteria for the "semi-vegetarian" category varied from "consumed red meat less than once a month, but included small amounts of poultry or fish in their diet" [11] to participants who "did not eat meat but ate fish" [10]. Also, the diet types varied and included vegan, lacto-ovo-vegetarian, lacto-vegetarian, semi-vegetarian, and macrobiotic semi-vegetarians. Lastly, some authors reported results for all participants as one group of vegetarians while others reported findings for separate diet type, age, and gender.

The criteria for the subcategory of "lacto-vegetarian" were more consistent with participants who "did not eat meat or fish but reported that they ate dairy products" [10] and "also excluded eggs" [19]. Similarly, the criteria for the subcategory of "ovo-vegetarian" were also consistent with participants who "had no restriction on eggs, but excluded milk products" [19].

It is important for clinical studies to use more than one biomarker when assessing the iron status because each of the biomarkers looks at the iron status in a different way. By combining the use of multiple biomarkers, a more complete picture of nutritional status can be obtained. By looking at the serum iron level and transferrin saturation, one can see how much iron is in the blood at that moment. Examining the ferritin level will show how much iron the body has in store and thus, ferritin level reflects what the long-term iron status of the individual has been.

The prevalence of iron deficiency was generally the lowest when Hb was utilized to assess the iron status. However, still in 5 out of 11 studies that used Hb as one of their biomarkers for iron status, the reported iron deficiency prevalence among vegetarians reached 18, 23, 23.1, 30, and 47.5%, respectively, indicating high deficiency prevalence [9, 12, 13, 15, 16].

When ferritin was the biomarker used to identify the iron status, the prevalence of iron deficiency also varied by study, with a considerably high percentage of vegetarians in some studies having a very low concentration. The lowest prevalence of deficiency was reported among Chinese vegetarian children, with 4.3% having ferritin concentration below 10 mg/L and 8.5% having ferritin concentration lower than 15 mg/L [18]. High prevalence of deficiency was reported among vegetarian children and adolescents from Canada (29.1% for lacto-ovo-vegetarians and 43.8% for semi-vegetarians), Great Britain (73% for ferritin <10 μg/L and 64% for ferritin <12 μg/L), and Poland (36.4% for ferritin <12 μg/L for children 1–3 years and <15 μg/L for children >3 years of age) [10, 11, 15]. The most troubling are results reported by Thane and Bates [9] in which as many as 64% of the youngest vegetarians (<3 years) had ferritin concentration below 10 μg/L and 73% with ferritin concentration below 12 μg/L. However, it is not clear whether these children were truly vegetarians, considering the authors' definition of vegetarian children (absence of all meat and meat products during the 4-day period).

In another study by Thane et al. [15], the reported prevalence of vegetarian girls from Great Britain with ferritin below 15 μg/L ranged from 20% among those 11–14 years old to 40% among 15–18 years old. Among boys, the prevalence by diet group was not reported. However, authors stated that no association between poor iron status and vegetarian boys was observed. Although the prevalence of inadequate ferritin concentration in this study is much lower than in the study by Thane and Bates [9], even in this study, vegetarianism was among 2 factors that was consistently and independently associated with poor iron status among girls. The diet type in this study was assessed using the 7-day diet recall.

In the third study from Great Britain conducted by Nathan et al. [16], a high prevalence of iron deficiency using Hb values was reported. Among the 50 vegetarian children 7–10 years of age, 29 adhered to this diet type for over 5 years, 14 were vegetarians for a length of 1–5 years and the others were vegetarians for a short period. The majority of these children were lacto-ovo-vegetarians, while 23 of them ate fish. As many as 47.5% of vegetarian children in this study had a Hb level below the 3rd percentile for Hb reference values for age and gender.

In contrast to the studies by Nathan and Thane, findings reported by Taylor et al. [20] showed very similar Hb and ferritin concentrations among vegetarian and non-vegetarian children from England. They assessed the iron status prospectively between 4 and 24 months of age. Hb values among 9 vegetarian children at 4–5 months of age were actually higher than among children in all 3 meat intake categories (120.3 vs. 112.9, 116.7, and 116.6 g/dL,

for low, middle, and high tertiles, respectively). The same was the case for the assessment done at 24 months of age (123.7 vs. 121.2, 121.3, and 121.7 g/dL). Similarly, ferritin level was higher among non-vegetarian children 4–5 months of age, compared to all non-vegetarian diet groups (49.5, 40.8, 37.7, and 41.4 μg/dL, for vegetarian, low, middle, and high meat intake, respectively). Interestingly though, Taylor et al. [20] found an inverse association between meat intake and the number of participants with low iron status assessed at 12 months of age.

The findings from 3 of the 4 above-mentioned British studies indicate that iron deficiency is a big problem among British vegetarian children. As already mentioned, ferritin concentration indicates the long-term iron status of individuals. Both the low ferritin concentrations and the high percentages of vegetarian participants with ferritin below iron deficiency and/or anemia cutoffs are indicative of a long-term poor iron status among these children and teenagers. Furthermore, one of the 3 studies also reported values for transferrin saturation [16]. They indicate a relatively high prevalence of inadequate iron supply. The findings showed low transferrin saturation among 20% of vegetarian girls 11–14 years and 60% among those aged 15–18 years.

When serum iron was used as the biomarker for iron deficiency, vegetarians and non-vegetarians had about an equal percent of participants with low serum iron. The exception is a study from Poland with a much higher percentage of non-vegetarian participants who had a low serum iron compared to vegetarians (22.2 vs. 4.5%) [10]. At least 3 of the 6 studies that used serum iron levels had more than 20% of participants that qualified as iron deficient [11, 12, 19].

The iron status in participants of the reviewed studies often reflected inadequate dietary intake. However, the discrepancies in iron status among vegetarian and non-vegetarian participants could not always be explained by intake differences. For example, according to data reported by Gorczyca et al. [10], intake of iron among vegetarian children equaled 65% of the recommended dietary allowance while it was 69% for non-vegetarian children. Yet, as much as 36.4% of the vegetarian group had low iron ferritin compared to just 11.1% among non-vegetarians. Although, vegetarian participants of some studies actually ingest higher amounts of iron, they mainly consume the less-bioavailable non-heme iron. Also, plant foods contain several potent iron absorption inhibitors [9, 16]. Furthermore, while vitamin C is considered to be an enhancer of iron absorption, the relatively high intake of vitamin C seemed to have had little effect on iron status among vegetarians. For example, in a study by Gorczyca et al. [10], even though the median intake of vitamin C among vegetarian children equaled 171.2% of the recommended daily allowance, which was almost double the median intake among non-vegetarians (94.7% of the recommended daily allowance), there was a significant correlation between vitamin C and iron intake only among non-vegetarians ($r = 0.87$, $p = 0.012$) but not among vegetarian children. These findings suggest that the iron-absorption inhibiting factors found in plant foods might be more potent than the vitamin C absorption iron-enhancing effect. Many vegetarians are advised to ingest vitamin C-rich foods along with iron-rich foods, to help with the iron absorption rate. However, the above-mentioned findings seem to indicate that moderate intake of dietary iron along with a high consumption of vitamin C are insufficient to obtain adequate ferritin and transferrin concentrations.

Early detection of iron deficiency in children is important so that the side effects of long-term iron deficiency may be avoided. Thus, vegetarian children should be routinely screened for their iron status. Also, although iron supplements are not recommended in a long-term use, periodic short-term use of such supplements may be helpful in preventing low iron status in vegetarians.

Our conclusions differ somewhat from those made by Gibson et al. [21]. They stated that Hb differences between vegetarian and non-vegetarian children are small and are rarely associated with anemia. This conclusion is only partly true. While the differences in the mean/median Hb values between vegetarians and non-vegetarians are small, as pointed out above, iron deficiency prevalence among vegetarians using Hb as a biomarker reached 18, 23, 23.1, 30, and 47.5% in some studies [9, 12, 13, 15, 16]. Also, vegetarians in some studies had a much higher deficiency prevalence using ferritin as a biomarker in several studies (Table 2) [9–11]. Thus, there seems to be a wide variation in the prevalence of inadequate iron status among vegetarian children and adolescents. The review by Gibson et al. [21], was based on 5 studies from industrialized countries, compared to 13 studies included in our review, regardless where the study was conducted. Thus, we believe that we present a more comprehensive evaluation of iron status among vegetarian children. Also, it would be a mistake to assume that vegetarian children from industrialized countries are free from developing inadequate iron status. In fact, big differences, in terms of prevalence of iron deficiency among vegetarian and non-vegetarian children, were found in 3 studies from

Great Britain and in a Canadian study [9, 11, 15, 16]. On the contrary, vegetarians from China had a low prevalence of iron deficiency, while those from Ghana actually had a better iron status than non-vegetarians from the same country [13, 18].

Saunders et al. [22] stated that vegetarians who eat a varied and well balanced diet are not at any greater risk of iron deficiency anemia, compared to non-vegetarians. They further stated that compared to non-vegetarians, vegetarians may often have lower serum ferritin but their ferritin is still within the normal range. Findings from several studied showed low, often below normal, ferritin levels among vegetarians. Thus, if their conclusion is accurate, it would have to be assumed that vegetarian children and adolescents included in these studies did not have varied and well balanced diet. A conclusion that iron status among vegetarians varies and depends on findings from specific studies seems more accurate. We agree with another conclusion made by Saunders et al. [22] that the physiological impact of low ferritin among vegetarians is unknown, although it is reasonable to assume that in some individuals erythropoiesis might be impaired.

Limitation

The conclusions based on findings from the reviewed studies are subject to a few limitations. The available studies were of relatively low quality. Most of them had a relatively small sample size. There was a wide variation in participants' age, which also makes it difficult to obtain a clear picture of iron status of vegetarian children in a specific developmental stage. Findings regarding individuals who adhere to specific vegetarian diet type, such as vegans, were underrepresented and thus, conclusions regarding iron status among such individuals were not possible. Although the studies were conducted in several countries, specific vegetarian centers/communities, such as Seventh-Day Adventists or Hindu Indians, were either not included or were underrepresented. Considering the limitations, it is reasonable to conclude that the findings are most likely not representative of the entire vegetarian populations nor are they representative of any one specific vegetarian subgroup (e.g., Seventh-Day Adventist, Hindu Indians). Also, 3 of the studies were published in the 1990s and one in 1982. It is reasonable to assume that iron fortification practices have changed since the time of food availability has improved due to globalization. Consequently, this makes the generalization of the findings difficult. Nevertheless, the observed overall pattern of vegetarians having lower iron stores and, higher deficiency prevalence in some studies, is likely valid.

Conclusion

In conclusion, inadequate iron status is a common nutritional problem among both children who follow vegetarian diet and those consuming non-vegetarian diets, although the problem seems to be considerably more prevalent among vegetarians. Iron status among vegetarians is likely a result of several factors. (1) The bulk of iron consumed by vegetarians is in its less bioavailable form, non-heme iron. (2) Plant foods contain potent iron-absorption inhibitors, including phytates, oxalates, and phenolic compounds. (3) Although iron intake among vegetarians is often higher than among non-vegetarians, iron requirements for vegetarians is about 1.8 times higher compared to non-vegetarians [5]. Thus, iron intake among vegetarians falls short of their needs.

Although vitamin C enhances iron absorption, relatively high intake of vitamin C among vegetarians does not guarantee adequate iron status. It would be prudent for vegetarians to utilize iron-fortified products. They may also benefit from periodic use of iron supplements.

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